Effect of Feed on Flavor in Dairy Foods

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ABSTRACT

Cattle diets that are low in lipids produce a hard milk fat high in the cheesy-flavored endogenous fatty acids and the precursors of the blue-cheese-flavored methyl ketones and of the coconut-peachy-flavored \( \delta \)-lactones. The reverse is true for high lipid diets. Diets that induce a propionate metabolism in the rumen cause the formation of the sweet, raspberry-flavored \( \gamma \)-dodecanolactone from dietary oleic acid and of the sweet, raspberry-flavored \( \gamma \)-dodec-cis-6-enolactone from dietary linoleic acid. Lush pastures produce a richly colored milk fat and introduce phytol, dihydrophytol, phytanes, and phytadienes, and probably their lower homologues, into the milk fat. A protein-free synthetic diet lowers the animal-flavored indole and skatole, eliminates 2-enals (C\(_3\) to C\(_{12}\)), and increases branched-chain and odd carbon-numbered \( \delta \)-lactones and branched-chain and odd carbon-numbered fatty acids in the milk fat. Milk from pasture-fed cows is less susceptible to oxidation than milk from cows on dry feed. Most cows will produce spontaneously lipolyzing milk if their plane of nutrition is sufficiently low; milk from well-fed herds is seldom susceptible to spontaneous lipolysis. Poor quality silage and various weeds produce off-flavors in the milk due to direct transfer of off-flavors, to the breakdown products of weed components, or to the effect of components of the weeds on the biochemistry of the cow.

(Key words: feed, flavor, dairy foods)

INTRODUCTION

There is a large body of anecdotal evidence about the desirable effect of spring and summer grasslands on the flavor of dairy products (64), but there is very little work defining this difference in the flavor in terms of definite flavor compounds. French workers (22) have shown that, for example, Gruyère de Comté typically contains sesquiterpene hydrocarbons in summer but not in winter. Dumont (16) compared samples of Gruyère de Comté made from milk originating from mountains, plateaus, or plains and showed that mountain cheeses proved to be the richest in volatile compounds and typically contained terpenes and sesquiterpenes. Neither of these groups of researchers actually analyzed the feed to see whether the differences were due to direct transfer of these compounds or whether the additional compounds were formed or modified in the cow. Lai (37) fed ewes a daily ration containing 2.7 g of pure oil obtained from distillation of 260 g of fresh Thymus herba barona Loisel and found that the milk had a pleasant aroma. They suggested that Thymus could be used as a natural flavoring for milk.

Recently Wilson (65) in New Zealand isolated the terpenes \( \alpha \)- and \( \beta \)-pinene, D-limonene, linalool, \( \alpha \)-terpineol, and carophyllene from New Zealand, but not from Finnish, milk fat and showed that 1 ppm of D-limonene, in particular, was responsible for the green/grassy flavor present in New Zealand milk fat at certain times of the dairying season. He also showed that the Finnish milk fat had higher levels of \( \gamma \)-dodecanolactone and \( \gamma \)-dodec-cis-6-enolactone than New Zealand milk fat, and he suggested that the sweeter flavor of European cheeses as compared with Australian and New Zealand cheeses was due to the \( \gamma \)-dodecalactones.

Taste substances may be transferred to the milk directly through inhaled air into the blood.
and from there to the milk; through the fodder and digestive system; by direct absorption from the digestive tract; or via rumen gases to blood and milk (51, 52). Ingested fodder constituents may or may not be changed biochemically (15, 50). Constituents of the fodder may affect the biochemistry of the ruminant and so develop flavors or off-flavors (7, 21).

During the 1960s I studied compounds responsible for the desirable flavor of butter. The main volatiles found in unheated milk fat were fatty acids, \( \gamma \)- and \( \delta \)-lactones, indole and skatole, phenols, and hydrocarbons with a phytane skeleton. Quantitative estimations were based on cold-finger molecular distillation of the milk fat followed by silicic acid column chromatography of the distillate and then gas chromatography of the fractions from the silicic acid column. This gave three major fractions: hydrocarbons, methyl ketones, and acids and lactones (56).

**EFFECT OF PROTECTED POLYUNSATURATED SUPPLEMENTS ON DAIRY FOODS**

In 1972, Scott et al. (49) in Australia, developed a method for producing ruminally derived products with elevated levels of di- and polyunsaturated fatty acids in the fat.

In a monogastric animal, such as horse, pig, chicken, or human, dietary fats are hydrolyzed, and the resulting fatty acids are used as such in the synthesis of depot fats and, in the case of lactating animals, in the synthesis of milk fats. In ruminants, however, unsaturated fatty acids are largely hydrogenated by the microorganisms in the rumen. They are then incorporated into the body fat and milk fat. Stearic acid is partly incorporated as such and partly as oleic acid. The oleic acid is formed by the action of \( C_9 \) to \( C_{10} \) desaturase on the stearic acid. This makes oleic acid the main unsaturated fatty acid of ruminant fat. Ruminant fatty acids usually contain only 2 to 4% di- and polyunsaturated acids, e.g., linoleic acid. Safflower oil, however, contains about 75% linoleic acid. Scott et al. (49) encapsulated droplets of such unsaturated oil in casein and then treated the casein with formaldehyde. This produced a casein-formaldehyde layer that is stable at the pH of the rumen (pH 6 to 7) and thus largely protects the oil against hydrogenation by the rumen microorganisms. But when encapsulated droplets reach the abomasum, where the pH is 2 to 3, the casein-formaldehyde layer breaks down and the unsaturated lipid is able to enter the blood stream by absorption through the small intestine. It is then incorporated into body and milk fats and produces ruminant fat, which may contain 20% or more linoleic acid. The exact amount of linoleic acid incorporated in the ruminant fat depends on the amount of protected supplement the animal ingests. Later, it was found that crushed oilseed could be used directly in the process of manufacturing the supplement. This eliminated the need for extracting the oil and reduced the amount of casein required. The crushed oilseed process was considerably cheaper and raised the possibility of making the project economically viable (49). At that stage, a company was set up to manufacture these products, which were then called ALTA.

Milk produced from cows receiving the original safflower oil and casein supplement was particularly susceptible to autoxidation. Oxidation in linoleic acid-enriched milk may lead rapidly to the production, from linoleic acid, of such compounds as hexanal and n-deca-2,4-dienal, whose flavor potency in milk is so strong that they may be detected at levels below .05 ppm. The rate at which oxidation occurs in linoleic acid-enriched milk varies with season and among individual cows, but the most important factor appears to be the nature of the supplement. Milk from cows fed on safflower oil and casein supplement developed oxidized flavor 24 h after milking, but the sunflower seed supplement produced milk that remained stable for 5 to 6 d before developing oxidized flavors (19).

Apart from being softer, polyunsaturated milk fat was paler than normal milk fat, reflecting fewer carotenoids (19). Butter flavor was flatter. Cheddar cheese made in the conventional manner from polyunsaturated milk developed much less flavor than cheese made from normal milk, possibly due to inhibition, by the linoleic acid, of the pyruvate dehydrogenase enzyme system in the cheese starter bacteria (2). When yogurt culture YB was used in combination with the normal starter, cheese flavor was satisfactory, although it was more reminiscent of Swiss cheese than of Cheddar (9).
EFFECT OF DIFFERENT FEEDS ON LACTONE AND METHYL KETONE PRECURSORS IN MILK FAT

The spectrum of volatiles of ALTA milk fat, i.e., milk fat high in linoleic acid, was examined. To generate lactones and ketones from their precursors in the milk fat, fat was heated at 180 °C in the presence of water vapor and the absence of air, before starting the cold-finger distillation. The changes brought about by heat are illustrated in Figure 1. The γ- and δ-hydroxyacid triglycerides are rearranged to form γ- and δ-lactones and diglycerides. The β-ketoacid triglycerides are hydrolyzed to β-ketoacids and diglycerides, and the β-ketoacids are then decomposed to methyl ketones and CO₂. Thus, this technique enabled us to analyze simultaneously for hydrocarbons and other preformed volatiles as well as precursors of lactones and methyl ketones.

γ-Dodecalactones

Both ALTA milk fat and ALTA meat fat contained unusually large quantities of γ-dodec-cis-6-enolactone. The structure of γ-dodec-cis-6-enolactone is shown in Figure 2. This lactone has an intense, sweet odor, reminiscent of artificial raspberry. This odor was not really objectionable in dairy products, first, because dairy products such as butter and cheese are usually not heated, and so the sweet lactone is not generated; and second, even when they are heated, as in the manufacture of cakes or biscuits, a sweet flavor is not objectionable. However, the flavor was very objectionable in meat, particularly in lamb, where it was very strong (43).

It was clear that the same factors were involved in the formation of γ-dodec-cis-6-enolactone in both milk and meat. Because milk samples are easier to obtain than meat samples, various experiments were designed to...
TABLE 1. Effect of different rations on the levels of γ-dodecalactones.1

<table>
<thead>
<tr>
<th>Ration</th>
<th>γ12:0</th>
<th>γ12:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Lucerne + crushed oats</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>Lucerne + crushed oats + protected safflower oil</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lucerne + crushed oats + protected sunflower seeds</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Lucerne</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Lucerne + expressed sunflower meal</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

1 γ12:0 is γ-dodecanolactone; γ12:1 is γ-dodec-cis-6-enolactone.

examine the effect of different feeds on the production of γ-dodec-cis-6-enolactone in milk. The ALTA animals were being fed on a 50:50 mixture of chopped lucerne hay and crushed oat grain plus the protected sunflower seed supplement. It was apparent that the sunflower seed supplement had something to do with the formation of the γ-dodec-cis-6-enolactone, but it was definitely not preformed in the protected supplement nor could it be formed from the supplement by the action of heat. We then set up an experiment with 14 cows that initially were all fed on pasture only (59). This gave a "normal" level for lactones and methyl ketones. Then all the cows were transferred to a basal diet of chopped lucerne hay plus crushed oat grain. The change from pasture to lucerne hay plus crushed oats increased the level of γ-dodecanolactone, i.e., the saturated analogue of γ-dodec-cis-6-enolactone, from 5 to 182 ppm without substantially affecting the level of γ-dodec-cis-6-enolactone. When we further introduced protected crushed oilseed supplement into the diet of 7 of the cows, γ-dodec-cis-6-enolactone increased from 1 or 2 ppm to 24 ppm, and at the same time, the saturated γ-dodecanolactone fell to 29 ppm. In the control cows, which received only the basal ration, the γ-dodec-cis-6-enolactone level remained low and the γ-dodecanolactone level remained high. In other words, the basal diet on its own produced a substantial change in the γ-lactone pattern, but it did not produce the unsaturated γ-dodec-cis-6-enolactone. The flavor threshold of the saturated γ-dodecanolactone is 1 ppm (60), and the flavor threshold of γ-dodec-cis-6-enolactone is of the same order (65). So, at the observed level of 24 ppm, γ-dodec-cis-6-enolactone is certainly a potent contributor to flavor.

In another experiment, we examined the effect of protected safflower oil (as opposed to protected sunflower seeds) together with the basal ration. This again raised the level of the saturated but not the unsaturated γ-dodecalactone. (The term "γ-dodecalactone" is used in this paper as a generic term to refer to both the saturated γ-dodecanolactone and the unsaturated γ-dodec-cis-6-enolactone.)

To summarize, lucerne hay on its own did not increase γ-lactones, nor did lucerne hay plus expressed sunflower meal (Table 1). Thus, we concluded it was the oil portion of the protected sunflower seeds that increased the γ-dodec-cis-6-enolactone.

Further work showed that the degree of protection of the oil was an important factor influencing the formation of γ-dodec-cis-6-enolactone. γ-Dodec-cis-6-enolactone could be formed only when there was access to unprotected oil in the rumen. McDowall (40), in 1957, found a sweetish foreign flavor in the milk and cream from cows that grazed on ryegrass and clover pastures and were drenched with 300 ml of linseed oil or peanut oil twice daily. It is highly likely that this sweetish flavor was due to one or both of the γ-dodecalactones.

E.F.L.J. Anet, of our division (3), suggested a mechanism for the formation of γ-dodec-cis-6-enolactone (Figure 3). Linoleic acid is hydrated in the rumen at the 9 to 10 position to 10-hydroxyoctadec-cis-12-enoic acid. This is broken down by three β-oxidations to 4-hydroxydodec-cis-6-enoic acid, which would lactonize spontaneously to γ-dodec-cis-6-enolactone. This mechanism accounts very nicely for the fact that the double bond retains the cis configuration, since it is derived from the cis-12 double bond of the linoleic acid.

A similar mechanism (Figure 4) also accounts for the formation of γ-dodecanolactone from oleic acid when oats are added to the diet. The oat oil contained 45% oleic acid and 37%
linoleic acid. The oleic acid provided the precursor for the γ-dodecanolactone (55).

The addition of oats to the diet had another effect. Diets with a high proportion of starch produce a change in rumen microflora — "propionate metabolism" — because during starch feeding, the ratio of propionate to acetate in the rumen is increased as compared with pasture or hay feeding, i.e., high roughage feeding. This change in rumen microflora includes the microorganisms that hydrate oleic acid and linoleic acid to the corresponding 10-hydroxyacids. Anet (3) found large amounts of 10-hydroxystearic acid in the rumen of sheep on a diet of chopped lucerne hay plus crushed oat grain. But when the experiment was repeated with lucerne hay as the sole dietary constituent, 10-hydroxystearic acid in the rumen was much less. In the same way, Anet found large amounts of 10-hydroxyoctadec-cis-12-enoic acid in the cecum of sheep whose diet included protected sunflower seeds in a basal ration of lucerne hay plus crushed oats. When the oats were left out of the ration, the 10-hydroxyoctadec-cis-12-enoic acid in the cecum was much less.

From these results it appeared that, for minimum production of both-γ-dodecalactones, oats and probably other cereals should be excluded from the basal ration and the supplement should have the highest degree of protection. This was actually confirmed in a flavor trial where the meat from sheep that had been fed protected sunflower seeds in a basal ration consisting only of lucerne hay did not develop sweet off-flavors on cooking.

We examined several other diets for their effect on the production of γ-dodecalactones. These diets and their effects are listed in Table 2. It seems that the choice of chopped lucerne hay plus crushed oat grain was quite fortuitous. This combination was almost the only one that did produce increased levels of γ-dodecanolactone.

Whey is a cheap source of carbohydrate, so we analyzed the milk fat from some cows whose pasture diet had been supplemented with 10 L of cottage cheese whey per cow per day, i.e., 2 to 3 kg of lactose per day. Neither the saturated nor the unsaturated γ-dodecalactone increased. This is consistent with the fact that diets containing a high proportion of glucose or sucrose tend to favor a butyric acid-type fermentation in the rumen, whereas diets containing a high proportion of starch generally result in a propionic acid-type fermentation (42).

Pasture hay plus crushed barley also did not increase the level of γ-dodecalactones. From these results, both the condition of the oats and the condition of the feed that goes with it determine the extent of production of the γ-dodecalactones.

The low fat syndrome and depression in milk fat content, from diets lacking fiber, are associated with the change to a propionic-type fermentation in the rumen (46). This change
TABLE 2. Effect of some other diets on the level of γ-dodecanolactone.

<table>
<thead>
<tr>
<th>Diet</th>
<th>γ-dodecanolactone level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture + 10 L of cottage cheese whey per cow/d i.e. 2 to 3 kg of lactose/d</td>
<td>1.7</td>
</tr>
<tr>
<td>Pasture hay + crushed barley</td>
<td>1.2</td>
</tr>
<tr>
<td>Restricted pasture + 5 kg whole oats per cow/d</td>
<td>2.7</td>
</tr>
<tr>
<td>Restricted short pasture</td>
<td>1</td>
</tr>
<tr>
<td>Restricted short pasture + whole oats</td>
<td>3</td>
</tr>
<tr>
<td>Restricted short pasture + crushed oats</td>
<td>42</td>
</tr>
<tr>
<td>Restricted lush pasture + crushed oats</td>
<td>1.3</td>
</tr>
</tbody>
</table>

also favors the production of γ-dodecalactone. When cows were fed on lush pasture plus crushed oats, γ-dodecalactone remained low, but when pasture was very short from excessive cropping, therefore lacking fiber, γ-dodecalactone rose to 42 ppm. During this period, the volatile fatty acids in cows with rumen fistulas were examined (Eldridge and Kat. unpublished data). Cow 1 was fed short pasture only, cow 2 was fed short pasture plus whole oats, and cow 3 was fed short pasture plus crushed oats. The ratios of (acetate + 2 × butyrate): propionate were 5.17, 4.86, and 3.55, respectively, indicating that only cow 3 had a propionate metabolism as indicated by an (acetate + 2 × butyrate): propionate ratio of less than 4 (42). Cow 3 was on the same feed as the cow that produced 42 ppm γ-dodecalactone. Wilson (private communication) was able to raise the levels of both γ-dodecalactones in milk fat by a diet of oats and sunflower seeds plus pasture. The increase was sufficient to influence flavor.
Figure 7. Suggested mechanism for the formation of δ-
10 tetradec-cis-8-enolactone from linoleic acid.

Figure 6. Some unsaturated lactones of milk fat.

Other Lactones and Methyl Ketones

Diet also affected the levels of other lactones and methyl ketones. We found that the lactone and methyl ketone spectrum of goat milk fat was qualitatively the same as the lactone and methyl ketone spectrum of cow milk fat, but the levels of saturated δ-lactones and methyl ketones from goat butter were only about one-third those of cow butter.

Figure 5 is a chromatogram of lactones from goat butter. This chromatogram also shows four lactones that had not previously been reported in either goat or cow milk fats: cis- and trans-δ-tetradec-8-enolactone, a conjugated cis,trans-δ-tetradecadienolactone, and an unconjugated cis,trans-γ-tetradecadienolactone. We also found these lactones in cow butter. In cow butter, we also found bovolide, dihydrobovolide, and hydroxybovolide (Figure 6). Of these lactones, δ-tetradec-cis-8-enolactone tended to increase with supplement feeding. By analogy with Anet's suggested mechanism for γ-dodecalactone formation (3), a possible mechanism for the formation of δ-
10 tetradec-cis-8-enolactone is the hydration of linoleic acid with the hydroxyl group being attached at the 9-position (instead of at the 10-position), followed by two β-oxidations (Figure 7). Such a hydration occurs in Wrightia seeds, where 9-hydroxyoctadec-cis-12-enoic acid is formed from linoleic acid under anaerobic conditions (1). Anet (3) did find a second unidentified hydroxyoctadecenoic acid in the rumen of a sheep fed on lucerne hay plus oats plus protected sunflower seeds.

Figure 8 is a chromatogram of the methyl ketones from C7 onward from goat milk fat (55). Total methyl ketones from C7 to C15 in goat milk fat ranged from 10 ppm when the goat was fed protected supplement to 35 ppm when the goat was fed chopped lucerne hay only. Equivalent values for cow milk fat were 37 to 193 ppm. The high values were obtained from cows fed crushed barley and pasture hay (57). According to the literature, the flavor thresholds of methyl ketones range from .5 to 8 ppm (20). This indicates that, in a product in which some or all of the methyl ketone potential is liberated as methyl ketones, e.g., in some cheeses, the source of the milk fat could make a big difference.

Whenever lipid supplements were fed, there was a reduction in saturated δ-lactones, methyl ketones, and fatty acids up to C16, i.e., fatty acids produced in the mammary gland rather than ingested. Such a positive correlation between δ-lactones, methyl ketones, and fatty acids up to C16 was also shown by Dimick et al. (13, 14) when they examined changes with season and with stage of lactation. All three
groups of compounds have been shown to be synthesized from acetate units in the mammary gland, and Dimick et al. (13, 14) thought that the amount of acetate in a common pool might have been a limiting factor, but Cook and Scott (8) suggested that the fatty acids ingested with the protected supplement inhibited biosynthesis.

Encapsulation allows the transfer of some flavors. When cows were fed on encapsulated mutton fat, the flavor of the mutton fat was transferred to the milk fat (CSIRO, unpublished data).

ISOPRENE HYDROCARBONS AND ALCOHOLS

Milk fat contains a series of polyisoprenes, the most abundant in the C_{20} region [hydrocarbons phyt-1-ene, phyt-2-ene, neophytadiene and its isomers (58), and the alcohols phytol and dihydrophytol (18)]. A high level of isoprenes is characteristic of pasture feeding. When animals were removed from pasture, the isoprenes were almost completely absent. In Australia, butter from King Island in Bass Strait is highly prized for its flavor. King Island has lush pastures almost year round; butter there has a high content of phytol and dihydrophytol (13 and 96 ppm, respectively, compared with no detectable phytol and of the order of 40 ppm dihydrophytol in mainland milk fat) (Urbach and Stark, unpublished data). Both hydrocarbons and alcohols appear to have been hydrogenated in the rumen, the likely source of the phyt-1-ene being the neophytadiene of the pasture and the likely source of the dihydrophytol being the phytol side chain of chlorophyll (58). Dihydrophytol probably does not in itself contribute to flavor, but there were indications of the presence of lower homologues, which could be flavorsome, as could the lower hydrocarbons. Larick et al. (38) found a similar decrease in the level of terpenoids in the body fat of steers when the steers were removed from pasture to grain feeding.

DIMETHYL SULFIDE

When cows consume feeds such as alfalfa, the dimethyl sulfide content of the milk increases (45). In low concentrations, dimethyl sulfide contributes to the characteristic flavor of raw milk, but in higher concentrations it causes a malty or cowy flavor defect (44). Sometimes the dimethyl sulfide content of milk is increased on heating, due to the breakdown of an S-methyl-methionine-sulfonium salt (34).

ZERO MILK

Virtanen et al. (62) fed cows in Finland an odorless, purified, protein-free diet consisting of cellulose, starch, sucrose, urea, and ammonium salts as nitrogen source to produce
“zero milk”. They (27) isolated the branched-chain 7-carbon lactone, trans-4-methyl-6-hexalactone from this zero milk at a level of 10 μg in 1 kg of zero milk fat; this is about 20 times the amount found in normal milk fat (Figure 9).

The odor of the compound resembles that of δ-heptalactone but is somewhat weaker. Honkanen (29) also found higher concentrations of odd carbon-numbered δ-lactones in zero milk than in normal milk and ascribed this to the increase in fatty acid synthesis by rumen bacteria that is caused by substituting protein in the feed with urea. The concentration of odd carbon-numbered and branched-chain fatty acids in milk fat also increased (61). There was no difference in lipase activity between zero milk and normal milk (26). Indole and skatole contents in zero milk were considerably lower than those in normal milk.

Schwartz and Virtanen (48) found the whole series of saturated aldehydes from C1 to C12 and methyl ketones from C3 to C13 in the volatile carbonyl fraction of normal and zero milk, but 2-enals from C3 to C12 were only found in normal milk.

The milk fat of zero milk is almost colorless because of the absence of carotene. Honkanen et al. (28) used a zero cow to feed 1 to 2 g of each of a series of aliphatic alcohols, aldehydes, ketones, and esters directly into the rumen through a tube passed down the throat of the cow and found that the maximum recovery in the milk was 0.05% of the amount fed, although the average recovery was much smaller than this.

EFFECT OF DIFFERENT DIETARY CEREALS ON THE OCCURRENCE OF BRANCHED-CHAIN AND ODD CARBON-NUMBERED FATTY ACIDS

Lambs given diets containing large amounts of rolled barley produce soft adipose tissue characterized by the presence of abnormally high proportions of odd carbon-numbered n-fatty acids and branched-chain fatty acids, which arise endogenously as a result of enhanced availability of propionate. This also is true for whole barley, wheat, or maize but not for whole oats (17). Formation of branched-chain and odd carbon-numbered fatty acids occurs to a greater extent in sheep and goats than in cattle and deer (21). The liver lipids of a wild baboon contained very small proportions of branched-chain acids, apparently derived from methylmalonate. The proportions were increased in vitamin B12-depleted animals, especially following the administration of a vitamin B12 analogue, which was antagonistic to vitamin B12 in its metabolic effects (47). 4-Methyloctanoic acid and its higher homologues are known to contribute to the characteristic flavor of mutton and goat meat (66), and 4-ethyl-2-enoic, which has a very strong goaty odor, was isolated from goat milk by the Givaudan Company (54). Recently, Ha and Lindsay (23, 24, 25) isolated several branched-chain fatty acids from cheeses made from the milk of sheep and goats.

LIPOLYSIS

Most cows will produce milk prone to spontaneous lipolysis if the plane of nutrition is sufficiently low, especially in late lactation, whereas milk from well-fed cows is much less susceptible. Thus, 2% protected safflower oil in the concentrate ration restored milk fat level of cows fed a high grain ration and reduced the rancid taste of their milk, although it increased the oxidized flavor (4). However, inclusion of 6% palmitic acid in a concentrate mixture significantly increased the free fatty acid content and rancid flavor of the milk (5). High incidence of lipolysis in late lactation may be related to the absence of pasture feeding or to dietary changes (12, 30, 31, 53).

OFF-FLAVORS

Many feeds cause off-flavors (Table 3). The betaine of beet by-products is converted to trimethylamine in the digestive tract of the cow and this gives milk a fishy flavor (10, 11). Trimethylamine is also responsible for the fishy flavor in milk from cows grazed on common rye and wheat (32). When onion pulp was incubated with rumen contents, substances appeared that gave rise to an off-flavor in milk (50). Many gramineous species are known to have an undesirable effect on the taste and smell of milk, and many legumes can transmit
bitter flavors to the milk. The same is true when these species are fed as hay. Many of the Cruciferae, when they are fed in large quantities, give the milk a sharp radish-like flavor and a penetrating smell. Fruit and fruit-and-vegetable residues have a deleterious effect on the odor and flavor of milk if they are fed in large quantities before milking, e.g., feeding of citrus meal can result in abnormal flavors in milk (6). There are many weeds that can give milk an unusual flavor or odor for up to 24 h after ingestion and, to make matters worse, some cows have a preference for weeds (36). To overcome these problems, Kezlinek (35) added .7 g of citronellyl ester of dimethacrylic acid to the daily feed ration of cows and found that this freed the milk of all organoleptic defects and also increased the rate of ripening of cheese and cultured milk products.

There is a tendency for dry feeding to promote the development of oxidized flavor, e.g., lucerne hay promotes the tendency of milk to oxidized flavor more than other forage crop species, whereas green or ensiled lucerne has a beneficial effect. Oxidized flavor is not always prevented by green feeding. There are different effects within individual groups of foodstuffs (36, 39). Milk from some herds develops oxidized flavor for no apparent reason, whereas other milk is quite resistant to oxidation. Spontaneous oxidation usually occurs in winter when cows receive no green feed. Feeding vitamin E sometimes alleviates the problem. The problem is still sufficiently serious to be considered by the International Dairy Federation (41).

**CONCLUSION**

I am convinced that milk fats in different parts of the world have a very different flavor and flavor potential, i.e., flavors produced when the milk fat is processed, such as by making milk into cheese. This has not become as obvious as it might because feeding regimens in different countries are fairly constant, depending on what is economic as a feed. It is natural that people should regard as “good” the flavor of milk fat to which they are accustomed and anything else as “off”. An example of this is the complaint by the Japanese that Australian and New Zealand butter is “animal” and lacks flavor (33). My reaction to a sample of “good” Japanese butter was that it was oxidized. Middle Eastern countries complain about the yellow color of Australian butter. They think that it is due to bacteriological action and will not be persuaded that the yellow color comes from lush pastures.

The work described indicates that the flavor of milk fat can be influenced by altering the feed of the lactating animal for a few days. Feeds high in lipid produce a milk fat in which the potentials of the coconut-flavored α-octalactone- and δ-decalactone, the peach-flavored δ-dodecalactone and the blue-vein-cheese-flavored methyl ketones are reduced. Conversely, an adequate low-lipid diet, e.g., one consisting only of lucerne hay, produces a milk fat in which these compounds are high. A starvation diet is similar to a high-lipid diet because the animal then uses body fat for milk production. A diet of chopped lucerne hay plus crushed oat

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**TABLE 3. Some feeds which produce off-flavors in milk (53, 63).**

<table>
<thead>
<tr>
<th>Feed</th>
<th>Cause</th>
<th>Off-flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beet by-products</td>
<td>Trimethylamine, formed from betaine in digestive tract</td>
<td>Fishy</td>
</tr>
<tr>
<td>Common rye and wheat</td>
<td>Trimethylamine</td>
<td>Fishy</td>
</tr>
<tr>
<td>Onion pulp</td>
<td>Action of rumen contents</td>
<td>Onion</td>
</tr>
<tr>
<td>Graminace</td>
<td>Action of rumen contents</td>
<td>Bitter principles</td>
</tr>
<tr>
<td>Legumes or legume hay</td>
<td>Mustard oil released during digestive fermentation</td>
<td>Sharp radish-like flavor, penetrating smell</td>
</tr>
<tr>
<td>Cruciferae</td>
<td>Lack of α-tocopherol</td>
<td>Off-flavor</td>
</tr>
<tr>
<td>Fruit and fruit-and-vegetable residues</td>
<td>Break-down products of benzyl-</td>
<td>Burnt, unclean, sharp, biting, cress</td>
</tr>
<tr>
<td>Dry feed</td>
<td>glucosinolate; benzyl mercaptan; benzyl methyl sulfide</td>
<td>pungent, scorched; herb-like</td>
</tr>
<tr>
<td>Poor quality silage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Cress</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
grain or a diet of chopped lucerne hay plus crushed oat grain plus oilseeds produces the potential for sweet raspberry flavor. Various feeds produce off-flavors. Underfeeding tends to produce spontaneously hydrolyzing milk and lack of either green feed or vitamin E tends to produce readily oxidizing milk. Milk fats should be selected for their flavor potentials. Milk fat for whole milk powder should have a low flavor potential, because the consumer preference for whole milk powder is one containing practically no lactones, methyl ketones, or free fatty acids, but these compounds are very desirable in butter cake shortening and in cheese.

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